EVERGREEN RESOURCE MANAGEMENT
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February 4, 2009

Mr. Douglas Cushman
Lahontan Regional Water Quality Control Board
2501 Lake Tahoe Blvd.
South Lake Tahoe, CA 96150

Re: Comments on Lahontan Region-Wide Timber Waiver Proposed Changes

Dear Doug:

The following letter and scientific study were sent to you during the informal comment period for this proposed change. I acknowledge several minor changes, including the allowance for the 1038(i) Forest Fire Prevention Exemption under Category 1. I am not sure how you can allow that exemption and not accept 1038(b), as well.

Please accept the following (letter dated December 4, 2008 to Mr. Douglas Cushman and the study titled "Impact of Slash Pile Size and Burning on Ponderosa Pine Forest Soil Physical Characteristics". Please reconsider how you re-structure this waiver.

Sincerely,

Mark A Shaffer

Mark A. Shaffer
President / California RPF # 2485
California LTO # A7052
Consulting Forester – Lassen County Fire Safe Council

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December 4, 2008

Mr. Douglas Cushman
LAHONTAN REGIONAL
WATER QUALITY CONTROL BOARD
2501 Lake Tahoe Blvd
South Lake Tahoe, CA 96150

Re: Lahontan Region-Wide Timber Waiver Working Draft

Dear Doug:

As you know, the Lassen County Fire Safe Council currently utilizes the Less than 10% Dead, Dying and Diseased trees of any size, fuelwood or split products…Exemption that is available to us through Cal-Fire. We are operating under 10 conditions specified in 1038(b) which allows for this work. Currently, we can go to work immediately upon sending a 1038(b) Exemption form into Cal-Fire. However, according to Lahontan Water Quality regulations (both existing and proposed), we are required to wait until we receive the Exemption back from Cal-Fire before sending in a Waiver Application to Water Quality. We can then be notified via phone that we can go to work, or, in the proposed regulations, we can go to work upon verified receipt by Lahontan.

<u>The biggest problem</u> with this is that CDF has to process up to 30 or more exemptions at a time from our organization alone, and get them approved and returned to us before we can submit Waiver Applications to Water Quality. Some time delays on the part of Cal-Fire have been up to 2 months.

Other problems include:

1. A 5 1/2 month working season imposed by Lahontan regulations that otherwise requires a Category 2 waiver (proposed has language addressing this, but includes increased monitoring requirements);

2. Various timeframes in which the grant funding for these projects is available. Some of these timeframes allow for no more than one working season, and if the money is not spent, it must be returned;

3. Due to the nature of our project, many landowners sign up when the equipment is one or two days away. Adhering to the regulations (existing and proposed) will leave many landowners out of the project, breaking up the continuity of the project and increasing costs dramatically.

Doug, you are aware that the Central Valley Water Quality Board utilizes the following language as it pertains to 1038(b) exemptions…

a. Timber harvest activities (Notices of Exemption or Emergency) within 150 feet of existing structures (i.e., "FireSafe" treatments), harvest of Christmas trees, dead, dying or diseased fuelwood or split products, public agency, public and private utility right of way, fuel hazard reduction, substantially damaged timberland unmerchantable as sawlog and woody debris and slash removal, that are conducted pursuant to a Notice of Exemption accepted by CDF under 14 California Code of Regulations (CCR) Section 1038, will automatically be enrolled in the Waiver.

This language allows the Cal-Fire Exemption to be the document that places us under the Waiver. We're subject to the same enforceable conditions, but the paperwork, process and time lags are taken away.

Additional Comments:

The current water quality Waiver limits the working season to May 1 through October 15 (5 ½ months). The normal working season for CDF is April 1 through November 15 (7 ½ months), with erosion control and weather-related operating restrictions between October 15 and November 15 and between April 1 and May 1.

Current Water Quality regulations are requiring that these operations from October 15 to April 30 be classified under a separate Waiver category, requiring extra paperwork and time. Proposed language requires additional monitoring on a daily basis that serves little purpose in protecting water quality. Adopting the language for operations during this time frame that is currently found in the Forest Practice Rules and allowing the Waiver to continue to be automatic would be beneficial. This language is as follows:

(1) Tractor yarding or the use of tractors for constructing layouts, firebreaks or other tractor roads shall be done only during dry, rainless periods where soils are not saturated.

(2) Erosion control structures shall be installed on all constructed skid trails and tractor roads prior to the end of the day if the U.S. Weather Service forecast is a "chance" (30% or more) of rain before the next day, and prior to weekend or other shutdown periods.

Any Operations between November 15 and April 1 could require a Category 4 waiver with monitoring.

Language pertaining to "Harvest or leave tree marking w/in Waterbody Buffer Zones by a Registered Professional Forester" needs to be reviewed by legal counsel to see if enforcement of this provision by Water Quality is possible without any RPF's on staff. Language may require tree cutting under the supervision of an RPF (also check with legal counsel) to help protect shade retention standards.

Language pertaining to chipped material being no more than 2 inches in depth is operationally infeasible. Often, material left as a result of chipping and/or mastication is larger than 2 inches. Alternative language should address an average overall depth with a maximum depth restriction.

These depths should be subject to discussion and review by RPF's prior to implementation by Lahontan. Again, an average depth with a maximum depth is much more realistic and enforceable.

14 CCR 937.3(c) reads as follows: ***Use of the broadcast burning prescription of the Stream and Lake Protection Zone for Class I, and Class II, is prohibited. Where necessary to protect downstream beneficial uses, the Director may prohibit burning prescriptions in Class III watercourses;...***

While broadcast burning within the WLPZ is prohibited, there is no restriction for piling and burning of hand piles within the standard width of a WLPZ. 14 CCR 937.5 (Burning of Piles and Concentrations of Slash) states this rather clearly. Not restricting hand pile burning within the WLPZ is purposeful due to its benign nature. A study of the effects of pile burning on the physical properties of soil is included for your review.

Finally, not to re-invent the wheel, I am in agreement with the comments made in the letter from W.M. Beaty & Associates, Inc., signed by Staff Forester Ryan Hilburn, in regard to this matter. I urge you to take these comments seriously and incorporate these changes into your proposed Waiver Application Process. If necessary, extra time should be provided for additional comments.

Sincerely,

Mark A Shaffer

Mark A. Shaffer
President
California Registered Professional Forester # 2485
Licensed Timber Operator # A7052

SEYMOUR, G., AND A. TECLE. 2004. IMPACT OF SLASH PILE SIZE AND BURNING ON PONDEROSA PINE FOREST SOIL PHYSICAL CHARACTERISTICS. *JOURNAL OF THE ARIZONA-NEVADA ACADEMY OF SCIENCE* 37(2):74-82.©2004GEOFF SEYMOUR AND AREGAI TECLE.

IMPACT OF SLASH PILE SIZE AND BURNING ON PONDEROSA PINE FOREST SOIL PHYSICAL CHARACTERISTICS

GEOFF SEYMOUR and AREGAI TECLE, School of Forestry, Northern Arizona University, Flagstaff, AZ 86001

ABSTRACT

Slash-pile burns associated with restoration thinning treatments may change soil characteristics resulting in broad implications for ecosystem functions, processes, and management. This study explores the impacts of size and burning of slash piles on various soil physical characteristics. At the Arboretum in Flagstaff, Arizona, the experiment consisted of burned, unburned, and control plots crossed with large and small sizes of slash piles. Slash from the unburned plots was removed and chipped for disposal elsewhere. The specific soil physical characteristics measured include water infiltration rate, soil moisture content, bulk density, and porosity. The results show no differences in water infiltration rates in the soils under the different treatments, leading us to conclude that burning slash piles did not form a hydrophobic layer in the soil. Soil bulk densities are lower, albeit insignificantly, in unburned pile plots than in burned pile and control plots. Hence, management decisions should recognize that the effects of burning piled slash during drought periods may be slight on these soil physical properties.

INTRODUCTION

Forest restoration has recently generated great interest among researchers and managers as a means of reducing the hazards of wildfire and forest health risks through thinning and prescribed burning (Brown et al. 1977, Snell and Brown 1980, Freeman et al. 1982, DeBano et al. 1998). Slash, unmarketable woody debris resulting from thinning, is often piled and then removed through either chipping or burning (Smith et al. 1997, DeBano et al. 1998). In most cases, prescribed burns remove the slash as well as most of the accumulated forest floor fuel load (Sackett et al. 1996, Covington et al. 1997, US Forest Service [USFS] 1998). Burning slash piles associated with forest thinning prescriptions may result in unintended effects on site characteristics in the treated areas. Severe soil damage can occur under these burn piles due to intense soil heating, however, the damage is limited to the local area under the piles (DeBano et al. 1998). Changes in soil physical characteristics created by either piling slash or burning the slash piles may contribute to floral community change, if not drive the change, by affecting water and nutrient pathways and light and water interception (Martin et al. 1979, DeBano et al. 1998, Neary et al. 1999). Therefore, physical changes in soils would likely result in habitat reduction for native fauna, and have broad implications for ecological functions, processes, and management. In spite of this, fire is considered an appropriate method to remove slash since wild fire historically consumed the dead fallen branches that comprise the majority of the slash piles (DeBano et al. 1998, USFS 1998). Land managers generally prefer to burn slash piles not only to reduce harvesting-related residual fuels that become fire hazards, but also because piles burn more efficiently with less smoke and are prudently burned under a broader range of weather conditions than broadcast burning of slash (Hardy 1966). In this study, we evaluate soil physical characteristics that can affect floral species establishment following slash pile burns associated with forest thinning treatments.

OBJECTIVES

Burning slash piles associated with forest thinning prescriptions may result in varying soil physical characteristics. Our objective in this study is to determine the effect of burning slash piles on soil bulk density, porosity, water infiltration capacity, and soil moisture content. We expect slower water infiltration in burned soils due to increased amounts of fine particles (ash from burned slash) that fill macropores in the soil and the formation of a hydrophobic layer resulting from intense heat that bakes the organic material in the forest floor. The expected increase in soil fines would increase soil bulk density while decreasing soil porosity. Furthermore, organic material has a large water-holding capacity, and consuming most, if not all, of the organic matter in and above the soil is expected to lower soil moisture conditions in burned plots.

Another factor that may affect soil physical characteristics is the size of slash piles. The US Forest Service has no specific guidelines for piling slash, therefore individual Ranger Districts pile slash as they see best fit for the area. Currently the Flagstaff area uses two sizes of hand-piled slash piles.

The Peaks Ranger District in the Coconino National Forest tends to build smaller piles, <1.5 m high and 3 m wide at the base, while the adjacent Mormon Lake Ranger District tends to build larger and wider piles, in excess of 3 m wide and at least 2 m high. Due to the increased amount of fuel wood and, subsequently, more heat production in the larger burn piles compared to the smaller piles, we further hypothesized that the expected effects described above will be greater under the larger piles than the smaller piles.

Study Area

The experiment was conducted on the grounds of The Arboretum at Flagstaff, approximately 10 km west of Flagstaff, Arizona, within the ponderosa pine (*Pinus ponderosa*)/Arizona fescue (*Festuca arizonica*) forest type. The slash piles were constructed from ponderosa pine slash material that was left on the forested grounds of the Arboretum. The slash piles were remains of a forest restoration thinning that occurred in 1999, in which approximately one third of the forest density was removed. The slash pile burning occurred in conjunction with further thinning in August 2001 by the Flagstaff Fuels Management Team, in which an additional third of the original basal area was removed.

Soils in the study area are typic or mollic eutroboralfs derived from flow and cinder basalt. The soils are classified as a Brolliar very stony loamforested, and contain approximately 40% sand, 40% silt and 20% clay (Arboretum site description compiled by the US Department of Agriculture's Natural Resources Conservation Service (NRCS), written communication). These soils tend to be moderately deep (50-100 cm) and have textures that range from a gravelly to a very cobbly loam (USFS 1995). Gravel is a rock fragment that ranges in size from 2 mm to 8 cm, while cobble ranges from 8 cm to 25 cm in size (Fisher and Binkley 2000). Rock fragments >2 mm make up more than 30% of the gravelly soils and half of the very cobbly soils. Generally, the slopes associated with these soil types range from 0-15%.

Precipitation over the area during the study period was low compared to the average from the last century. The slash piles were burned and soil samples were collected in 2001 during which a total of 44.58 cm of precipitation fell (data from Pulliam Airport, Flagstaff). During the period between burning and sample collection, the study site received very little precipitation.

SOIL PHYSICAL CHARACTERISTICS

Soil Bulk Density and Porosity

Blake and Hartge (1986) define bulk density (grams/cm^3) as the ratio of the mass (g) of ovendried soil solids to the bulk volume (cm^3) of the solids plus the pore space, with the moisture content present during the sampling period. Bulk density can be used to calculate soil porosity (pore space in a soil), convert soil weight to volume, and estimate weight of soil at the landscape scale (Carter 1993). To calculate soil porosity, divide bulk density by the particle density of the soil. Particle density (g/cm^3) simply refers to the density of soil particles without any consideration for the volume of pore space in the soil. The particle density of mineral soil is generally approximated at 2.65 g/cm^3, since that is the particle density of quartz—a dominant component of mineral soils. The ratio of dry bulk density to the soil particle density gives the fraction of the total space occupied by solid material. Subtracting this ratio from 1.0 gives the pore space in the soil. Hence the formula:

$S_t = [1 – (D_b/D_p)] * 100$

Where S_t is the Total Soil Porosity (%), D_b is Dry Bulk Density (g/cm^3), and D_p is Soil Particle Density (g/cm^3). Soil porosity in mineral soils may vary from 20 to 70%.

Infiltration Capacity

Infiltration is an interfacial process in which water enters the soil from the surface and moves downward (Hillel 1971). Infiltration capacity is the maximum rate of infiltration that can pass through the soil under standing water conditions. This rate is quite important since it often determines the amount of runoff that might occur after a rain event or snowmelt (Hillel 1971). But perhaps more importantly, infiltration capacity determines the quantity and rate at which surface water becomes available to plants. Knowledge of the infiltration rate can be used to identify soil properties such as relative bulk density, porosity, compaction and hydrophobicity below the soil surface. In this study, we use infiltration capacity to determine whether hydrophobic compounds in the soil created a water repellent layer that would, at least momentarily, seal off, or retard infiltration. If a water repellent layer exists, infiltration capacity can also help determine the relative depth of the hydrophobic layer associated with a given treatment.

When a hydrophobic layer is reached, the rate of the infiltrating water rapidly decreases and approaches zero. Once the wettable soil layer is saturated, pressure from the hydraulic head, at the boundary of the wetted and water-repellant layers would increase by the lack of downward or lateral movement of water (DeBano et al. 1998). Eventually this pressure would induce failure in the hydrophobic layer allowing infiltrating water to penetrate past the hydrophobic layer. The failure in the hydrophobic layer would be reflected by the infiltration rate increasing as water saturates the deeper soil, then decreasing to some long-term constant that represents the deep percolation rate.

Soil Hydrophobicity

One of the most significant physical alterations that may occur in burned soils is an increase in soil water repellency. Water repellency in soils was first observed in the mid-1800's (Bayliss 1911). Those early observations related soil-water repellency to soil fungi (specifically mycelium structures). A phenomenon that drew the attention of researchers during that time was a condition known as a "fairy ring," which describes an approximately circular spatial formation of plants where growth inside the circle appears stimulated. The formation could be so distinct that outside the circle, only bare ground or withered plants occur. In the late 1800's soil moisture was found to be the reason for the formation of such rings. The soil moisture inside the circle of healthy plants was higher than that of the surrounding soil (Lawes et al. 1883). Molliard (1910) reported that soils with mycelium fungi contained only 5-7% soil moisture, compared to 21% in similar areas without the mycelium fungi. Bayliss (1911) provided a case study in which rain water could not penetrate through mycelia-infested soils, while it penetrated through similar, mycelia-free, soils to a depth of 10 cm. Other mechanisms (such as volatilizing organic materials) may be responsible for the formation of any post-fire water repellency in the ponderosa pine forest type. Water repellent soil (hydrophobic soil) is often found on the surface or a few centimeters below and parallel to the surface (DeBano et al. 1998), characteristically under a layer of severely burned soil or ash (DeBano 1969). Intense heat pushes vaporized organic compounds downward into the soil until they reach cooler soil layers and condense. The organic compounds then coat soil particles, which in turn adhere to each other forming a hydrophobic barrier. Research into fire-induced hydrophobic soils began in the 1950's and accelerated in the 1960's (DeBano 2000a, 2000b). Shortly thereafter, DeBano and Krammes (1966) hypothesized that organic compounds coated soil particles more efficiently at lower temperatures lasting shorter time periods, than at higher temperatures lasting longer periods since high temperatures and long periods tend to destroy the organic compounds (DeBano et al. 1998). Subsequent investigations showed that (1) water repellency changes very little when soil temperatures are <175°C (DeBano 1981, Neary et al. 1999); (2) heating between 175 and 200°C creates intense water repellency (DeBano 1981, March et al. 1994, Neary et al. 1999); (3) destruction of water repellency occurs when soils are heated between 280 and 400°C (Savage 1974, DeBano et al. 1976, March et al. 1994, Giovannini and Lucchesi 1997); and (4) at temperatures of $450°C, virtually all organic material in the soil is consumed (Neary et al. 1999). An important caveat here is that hydrophobic layers produced during fire can vary greatly due to differences in fire intensity and soil characteristics.

STUDY METHODS

Field Measurements

This study investigated burning effects of handpiled slash on soil physical characteristics because much of the forest thinning and fuel reduction currently conducted in the Flagstaff, Arizona, Urban/ Wildland Interface Program involves hand-piled slash burning by the Fuels Management Team of the

City of Flagstaff Fire Department. We constructed experimental plots to evaluate the effects of burning two different sizes of slash piles on soil physical characteristics from the perspective of bulk density, porosity, and infiltration capacity and soil moisture content.

Plot Selection and Pile Construction

Prior to constructing slash piles, plots were randomly assigned within each study block with the provision that piles on those sites would burn safely. We avoided sites directly below or immediately upwind of tree canopies, or those sites in close proximity to other slash piles. Two sizes of slash piles were constructed. Small piles were round at the base, 1.2 m high, and 2.4 m in diameter, while large piles stood 2 m high, 4 m wide and 5 m long forming an oval or oblong shape. Piles were constructed from various sizes of slash, including needle litter, branches, and poles that were too small (<15 cm in diameter) to be removed by the harvesting crew during the 1999 thinning. Slash was grouped into size classes (i.e., 1-3, 4-7, 8-11, 12-15 cm sizes) and the percentage of each experimental pile made up by each size class was determined by measuring the slash pile material at the Northern Arizona University's (NAU) Ecological Restoration Institute and the School of Forestry's research area in Fort Valley

Figure 1. *Soil bulk density versus treatment types. Similar letter indicates an absence of a significant difference (a = 0.05). While the burned plots did have a slightly higher bulk density compared to the other treatment plots, the differences were not significant.*

outside of Flagstaff. This process ensured that our experimental slash piles were similar to each other and to piles in other areas surrounding Flagstaff.

Soil Infiltration Capacity

Infiltration rates were measured using a doublering infiltrometer after sampling the soils in the burned, unburned, and control plots. Infiltration rate measurements took place near the center of the plots but not adjacent to the soil sampling spots. We analyzed the data to determine whether or not burning had any effect on soil infiltration capacity. If burning had created hydrophobic soils, then the rate of infiltration would have temporarily approached zero after the overlying soil became saturated.

Moisture Content

Discrete values of soil moisture content were measured using time domain reflectometry (TDR) (Soil Moisture Equipment Corp. 1996). We inserted probes of 15 cm in length vertically into the ground near the center of every plot as well as at points 60 cm outside the plots. Since data collection with TDR is simple and quick, it was practical to measure outside the treatment plots to help determine any variations in soil moisture content between treatment plots and untreated sites or controls. This measurement occurred at the same time soil samples were gathered for laboratory analysis.

Bulk Density

Bulk density is a measure of the amount of soil particles (matter) in a volume of soil. The core method was used to calculate bulk density (Carter 1993). Soil pits were dug to about 15 cm deep near the center of each plot. The soil was scraped away from one of the walls to access undisturbed soil. The corer was placed horizontally against this undisturbed wall of soil, centered at 5 cm of depth, and tapped into the undisturbed soil column. Soil cores were thereby extracted from a single layer of soil. The ends of the cores were then capped (to maintain the cylindrical volume of the soil sample) and transported to a laboratory at NAU for analysis.

Laboratory Analysis of Bulk Density and Soil Porosity

Soil cores were weighed and then oven dried in their tubes for 72 hours at 105°C. Bulk density (g/cm3) was then calculated by dividing the weight (in grams) of the dried soil by the bulk volume (in cm3) of the soil core (Carter 1993). Total soil porosity was calculated by dividing the dry bulk density by the soil particle density value of 2.65 g/cm3, which is common for mineral soils like those in the study site (Carter 1993).

Statistical Analysis

The final infiltration rates of the treatment plots were compared to each other using SPSS (SPSS 11.5, SPSS Inc. 2003). Treatment effects were analyzed using one-way ANOVA comparisons of the infiltration rates in each treatment type (large, small, burned, unburned and control). We ran normality and homogeneity of variance tests and accounted for alpha inflation using Tukey's Honestly Significant Difference (HSD) (Zar 1999). In this study we selected a statistical significance level of "=0.05.

RESULTS

Soil Bulk Density

The bulk density values of the soils in the entire suite of treatment plots and the control ranged between 1.1 g/cm^3 and 1.24 g/cm^3 (Fig. 1). This range is very tight with little variation between treatments, and shows no significant differences in bulk density between any of the treatments at the 95% confidence level.

Soil Porosity

In this study, we determined porosity from soil bulk density and soil particle density values. Because there was no significant difference in the bulk density values, we do not expect the porosity values to differ significantly from each other. Table 1 displays the lack of significant difference in soil porosity values between any of the treatments at the 95% confidence coefficient.

Soil Infiltration Capacity

Table 2 displays distinct differences in infiltration capacity measurements between treatments (p=0.02). Large burned and unburned pile plots had significantly greater infiltration rates than that of small unburned plots (p=0.050 and 0.019, respectively).

However, the patterns of infiltration showed no distinct differences between treatments. All treatments had high initial infiltration rates that reduced to a constant rate within a short period of about 15 minutes (Fig. 2). Typically, the infiltration rate values become constant at about 2 liters (L)/hr. The resulting pattern indicates the absences of any significant formation of hydrophobic layers in the soils.

Soil Moisture Content

The test for soil moisture content shows no significant differences between individual pile sizes, treatment types, and soil moisture contents inside and those outside of the plots (Table 3). However, there are some significant differences in soil moisture content between interactions of size, treatment, and inside/outside conditions. One such difference is between the soil moisture contents of large, burned pile plots (L+B) and that of small, unburned (S+Unb) pile plots (p=0.049) (Fig. 3). Soil moisture conditions inside L+B plots also differed significantly from the conditions outside the S+Unb plots (p=0.047). However, there are no significant differences between the soil moisture contents of L+B and that of small, burned (S+B) pile plots or between L+B and large, unburned (L+Unb) pile plots. There are also no significant differences between the soil moisture contents of the control plots and either the L+B or S+Unb plots. Inconsistent variation in soil moisture conditions in these comparisons may be more due to microsite differences than due to differences between treatments.

Other noteworthy differences exist, but differences are at, or around the 0.10 confidence level. These differences are between the soil moisture contents of large, burned plots and those of large, unburned plots (p=0.06), as well as between moisture contents of small burned plots and large burned plots (p=0.11). Similar differences were observed between soil moisture conditions outside the treatment plots. These differences are between soil moisture contents outside small burned (S+B) plots and those outside L+B plots (p=0.11), between those outside S+B

Table 1. *ANOVA Test results showing no significant differences in soil porosity between treatment types.*

Source	df	Sum of squares	Mean square	F value	Pr>F
Model	13	346.165330	26.628102	1.37	0.2198
Error	36	698.278520	19.396626		
Corrected total	49	1044.443850			

R^2=0.331435
Coefficient of variance = 7.823637
Root MSE = 4.404160
Porosity mean = 56.29300

Table 2. *ANOVA Test results showing significance in water infiltration capacity differences between treatment types at final infiltration test period (after 111 minutes).*

	Sum of squares	df	Mean square	F	Significance
Between groups	7.160	4	1.790	3.264	0.020
Within groups	24.676	45	0.548		
Total	31.837	49			

plots and outside S+Unb plots (p=0.06), and between those outside S+B plots and outside the control plots (p=0.08).

ANALYSIS OF RESULTS

Soil Bulk Density/Porosity

The results of this study failed to support our

hypothesis that fine particles from wood ash would increase soil bulk density. The absence of significant differences in soil bulk density or porosity values across treatments is intriguing since the fires consumed over 95% (as estimated by the City of Flagstaff Fuels Manager) of the organic material in the burned slash piles. This almost complete burning of the slash piles resulted in copious accumulation of ash in the burned plots. The ash should have introduced
a large amount of fine particles into the soil macropores and thus affected the soil bulk density and porosity values of the plots regardless of compaction
or heat effects from fire. Further, fires that generate ground temperatures between 220-460°C can consume the organic matter in soils, deteriorating the soil structure (DeBano et al. 1998). Such deterioration in soil structure in turn would decrease the amount of soil macropores. Since macropores are largely responsible for the rate of water infiltration into soils, any soil structural deterioration that reduces the amount of macropores would lead to a reduction in infiltration rates (Neary et al. 2003). Nonetheless, no such effect appeared in this study. The lack of changes in infiltration rates between treatments is most likely due to (1) the very cobbly structure of the soils, which creates channels for water movement (Brady and Weil 1996), and (2) the absence of changes in soil bulk density and porosity.

Soil Infiltration Capacity

The results of this study also fail to support our hypothesis that increased fine materials from the burned slash would affect the soil infiltration capacity in two ways: (1) the fine materials would plug the porous space through which water moves and (2) form a hydrophobic layer below the surface that retards downward water movement. However, we did not see such effects in this study. While distinct differences exist in infiltration capacity between different treatments, the changes in infiltration rates remain the same across all treatments (Fig. 2); after the first 18 minutes the infiltration rate in each experimental treatment remained almost constant at 1.0-2.2 L/hr. The changes in infiltration rates in the control and unburned plots did not differ from those in the burned plots. This indicates the absence of any significant formation of a hydrophobic layer. Even large, unburned plots, which had considerably higher initial infiltration rates, showed rates similar to the other treatments after the initial three minutes. Possibly, fine particles of ash and organic material left on the soil surface did not enter into the soil to clog the macropores and produce hydrophobicity because of the lack of precipitation needed to trans-

0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000
16.000
18.000
20.000
0 3 6 9 12 15 18 21 24 27 30
Time (min.)
Infiltration Rate (l/hr)
Small Burned
Large Burned
Small Unburned
Large Unburned
Control

Figures 2. *Infiltration rate (l/hr) versus time (in minutes) during a 30 minutes period. Extension of the period of infiltration test (not shown) indicated some significant differences in the final, constant rates of infiltration in the large burned and unburned plots compared to those in the small unburned plots (a = 0.05).*

port those fines down to some uniform layer. Also, rapid wind speeds sometimes prevalent in the study area might have blown most of the wood ash off the study plots before the ash could penetrate into the soil. However, a more probable explanation for the lack of hydrophobicity is that since slash pile fires often produce temperatures from 500-700°C at and slightly below the soil surface, any organic compounds on or near the surface would have been incinerated, thus prohibiting the formation of a hydrophobic layer (Rundel 1983, Neary et al. 1999). As heat from the burning slash penetrated downward through the soil column, soil at some depth would have experienced temperatures between 175-250°C. These temperatures would vaporize any hydrophobic compounds present into gases that can coat the soil particles (Savage 1974, DeBano et al. 1976, March et al. 1994, Giovannini and Lucches 1997). Roberts (1965) found that slash-pile burning can generate temperatures exceeding 250°C as deep as 10 cm in mineral soil. Consequently, while soil layers somewhere
below approximately 5 cm would have experienced temperatures between 175-250°C, these soil

layers were probably too deep to have enough organic matter to form an uninterrupted hydrophobic layer.

Soil Moisture Content

The results of this experiment also fail to support our hypothesis that soils in burned plots would have lower moisture contents than soils in unburned or control plots due to the consumption of organic matter, which has large water holding capacity. Soils in large, burned pile plots (L+B) had significantly less moisture content than those outside the small, unburned (S+Unb) pile plots. However, analysis of the main effects of burning and size show that neither result in significant differences. There were also no differences between the controls and either the L+B or S+Unb pile plots. Thus the difference appears to be due to an interaction of size and treatment, however soil moisture data from outside the plots suggest otherwise. Soil moisture content inside the S+Unb plots was similar to the moisture content outside the S+Unb plots (Fig. 3). Therefore site conditions probably affected the moisture conditions of small unburned plots more than any effect from treatment interactions.

CONCLUSIONS AND RECOMMENDATIONS

In much of the southern Colorado Plateau, burning slash piles is generally conducted in association with forest restoration thinning. Although ground and belowground temperatures were not measured in this study, descriptions of high-severity fire effects (including reddish mineral soil, complete consumption of duff and logs as well as extended char layers) match conditions of burned slash pile plots in the area (Albini et al. 1996, Hungerford 1996, DeBano et al. 1998). Soil temperatures under high severity wildfires can exceed 250°C (DeBano et al. 1998, Neary et al. 2003), while slash pile temperature can exceed 500°C slightly below the soil surface (Rundel 1983, Neary et al. 1999). The severe nature of these burns explains some of the physical properties observed after the slash piles burned.

The changes in soil physical characteristics observed in this study do not appear to conflict with forest restoration goals. Although some differences did exist between burned plots and unburned plots, generally the differences did not show any patterns and often they did not exist between treatments and controls. Water infiltration rates (Fig. 2) exemplified this point since the rates associated with most of the treatments differed significantly, yet all of the treatments displayed the same pattern of high initial infiltration rates that decreased quickly to a constant rate. Assuming the slash pile burn effects were severe, this lack of hydrophobicity is consistent with other studies that state that water repellency is destroyed when soil temperatures exceed 288°C (Savage 1974, DeBano et al. 1976). Further, the results suggest that the amount of ash fines, from the burned piles, entering the macro-pores in the soil was insufficient to alter infiltration rates. This corresponds to the results displayed by soil bulk density analysis. Bulk density did not indicate the expected increase associated with soil compaction from piling the slash, nor did bulk density increase in the burned plots due to entry of fine ash particles (Fig. 1). The situation with porosity is the same, since porosity values were determined from the bulk density values.

Soil moisture content displayed a different situation (albeit not significant) between the large, burned pile plots and the large, unburned pile plots (p=0.06) and this implies a potential effect of intense burns of long durations on the soil. However, soil moisture within large, burned plots failed to differ from the moisture content in controls adjacent to, and outside of, the large, burned plots (p=0.614). Moisture levels in large, burned plots also failed to differ from moisture levels in control plots (p= 0.814). According to these results, soil moisture is not significantly affected by the treatments in this study. This result is inconsistent with the idea that newly burned soil surfaces would have increased evaporation due to increased temperatures caused by increases in unimpeded solar radiation falling on the soil surface (Christensen and Muller 1975, Pickett and White 1985, Neary et al. 1999). The extremely low amount of precipitation during the time between

burning and sampling the soil moisture could have a major influence on our findings. Our findings may also reflect the theory that a decrease or absence of interception by vegetation and OM may result in decreased evapotranspiration of water (Bosch and Hewlett 1982, Whitehead and Robinson 1993, DeBano 1998).

Research in the 1960's and 1970's suggested that non-ionic wetting agents could be beneficial in counteracting any hydrophobic layer created in soils. Wetting agents have been effectively administered onto soils after intense wildfires in a reasonably successful effort to reduce erosion and runoff (DeBano 2000b). Hydrophobic layers caused by wild fires can exist across landscape scales, and amending the soil to prevent erosion and induce percolation is definitely warranted. However, results in this study, which are based on data from a single dry year, indicate that restorationists and other land managers may not need to amend or treat the soil to offset physical changes from burning hand piled slash since no dramatic effects were observed. This conclusion should be taken cautiously since continued observation of the treatment plots is necessary to witness longer-term effects over different climatic conditions.

A major goal of forest restoration treatments in the Southwest is to thin the ponderosa pine overstory in an effort to reduce catastrophic wild fires as well as to promote understory health to levels of diversity and structure that are both socially and ecologically desirable. We must be careful that the methods we use to restore these forests do not compromise the overall goals that we strive to achieve. To this end, it is important to uncover the mechanisms that may or may not result in habitat reduction for native fauna, and have broad implications for ecological functions, processes, and management. This study has demonstrated that initial (first year) changes in soil infiltration capacity, soil moisture content, bulk density and porosity due to burning of slash piles are not causal mechanisms for habitat reduction since profound changes in these soil characteristics did not occur.

ACKNOWLEDGMENTS

We thank The Arboretum at Flagstaff, and Flagstaff Fire Departments Fuels Management Crew. Support for this study came from the Bureau of Land Management (Grant # PAA-01-7002) through the Ecological Restoration Institute at Northern Arizona University, the State of Arizona Proposition 301, the National Science Foundations Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) (Grant # Y542104), and the USDA Forest Service, Rocky Mountain Research Station (Grant # 01-JV-11221606-214).

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